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ATTEMPTS TO IMPROVE VISUAL DETECTION THROUGH USE OF SEARCH PATTERNS AND OPTICAL AIDS

Robert D. Baldwin

Human Reseouces Research Organization

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13. ABSTRACT
The research objectives were to compare the visual detection abilities of observers equipped with low- and moderate-powered optical systems, and to compare the detection capabilities of observers using different techniques or strategies for searching extensive visual displays. Visual experiments were conducted in a scaled reduction of an aircraft detection situation, comparing observer results using optical aids and unaided vision; a general conclusion was that "sharp" eyes are the best visual detection aids. Several search patterns experiments compared unstructured and structured visual search for simulated aircraft targets. Fundamental characteristics of vision—visual acuity and field of view—appear to be the major sources of variance in aquiring visual targets.

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The Human Resources Research Organization (HumRRO) is a nonprofit corporation established in 1969 to conduct research in the field of training and education. It is a continuation of The George Washington University Human Resources Research Office. HumRRO's general purpose is to improve human performance, particularly in organizational settings, through behavioral and social science research, development, and consultation. HumRRO's mission in work performed under contract with the Department of the Army is to conduct research in the fields of training, motivation, and leadership.

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II

FOREWORD

The research reported herein was accomplished by the Human Resources Research Organization as part of Work Unit SKYFIRE, which has been concerned with ascertaining the visual skills of operators of low-altitude air defense weapon systems. Previous reports have described field and laboratory research concerning visual detection, aircraft recognition, and ranging and tracking skills. The present report describes research to evaluate (a) optical aids for visual detection of simulated aircraft, and (b) techniques of visual search.

The research was conducted at HumRRO Division No. 5, Fort Bliss, Texas, where Dr. Albert L. Kubala is Director.

Military support was provided by the U.S. Army Air Defense Human Research Unit. The Military Chief was LTC F.R. Husted.

The research was conducted by Dr. Robert D. Baldwin, with the assistance of Mr. Robert J. Foskett. Military research and engineering assistants were SP5 D.M. Lee, SP5 W.J. Given, SP5 E.E. Chadwick, SP5 P.D. Waldo, SP4 W.J. Scaife, SP4 G. Kavanagh, PFC T. Parham, and PFC W.P. Schliemann.

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Meredith P. Crawford
President
Human Resources Research Organization

SUMMARY AND CONCLUSIONS

MILITARY PROBLEM

A number of field experiments have been conducted in recent years to determine the capabilities of ground observers to detect low-flying aircraft. These studies have used both unaided vision and moderate-power optical aids for the detection function. Results have indicated that the moderate-power optical aids did not facilitate aircraft detection; in fact, in some instances detection was handicapped through the use of such aids. In addition, these studies suggested that detection performance may be significantly influenced by the patterns of search employed by ground observers.

As a result of previous research, the U.S. Army Combat Developments Command Air Defense Agency expressed an interest in evaluations of low-power optical aids, such as two- to three-power monocular and binocular systems, that might be used for initial detection. Such low-power optical assists, because they possess a wider field of view than is characteristic of moderate-power binoculars (such as 6X30 and 7X50), might not demonstrate the degradation of detection that had been shown by earlier studies. In addition, the Air Defense Agency and the U.S. Army Air Defense School expressed an interest in research to evaluate various strategies for searching large visual displays such as sky and horizon.

RESEARCH OBJECTIVES

The objectives of the research were to compare (a) the visual detection abilities of observers equipped with low- and moderate-powered monocular and binocular optical systems, and (b) the detection capabilities of observers using different techniques or strategies for searching extensive visual displays.

RESEARCH METHOD

Optical Aids

A series of visual experiments was conducted using a 1000-to-1 scaled reduction of an aircraft detection situation. For these tests, black spherical targets, which subtended less than one minute of angle, were presented in front of a white background screen, which subtended 1,100 mils horizontally and 200 mils vertically. For a majority of the tests involving the comparison of optical aids, the luminance of the background screen varied between 45 and 80 foot-lamberts, which was slightly darker than the illumination level characteristic of an "overcast day."

The first test concerning aids involved a comparison of four optical systems:

(1) A U.S. Government-Issue 7X50 binocular.
(2) A 2 1/2X monocular scope made in Japan.
(3) A second Government-Issue 7X50 binocular that was modified to reduce the amount of luminance transmitted to the eye to approximate that of the 2 1/2X scope.
(4) An inexpensive 7X35 wide-angle binocular, also made in Japan.

Five observers used each of these optical systems. During the one-hour testing session for each observer, 12 targets were presented at random places in front of the screen and at

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random time intervals. No warning was provided concerning the time or place of appearance of a target. The time lapse between presentation of the target and its detection by the observer was used as the performance measure.

The second test of optical aids compared a 3X monocular system that was manufactured in the United States and the unmodified 7X50 binocular. The characteristics of the test situation were identical with those established for the first test, except that each observer used each optical system during two successive 30-minute test intervals. During each 30-minute period, six targets were presented at random times and places.

A small-scale third experiment was conducted that compared the 3X monocular system with unaided vision in high illumination (outdoor) viewing condition.

Search Patterns

Four experiments were conducted concerning techniques of visual search. These experiments also used the 1000-to-1 laboratory simulation of an aircraft detection situation. Only unaided visual search was employed for these experiments. The test characteristics established for the search experiments were similar to those employed for the optical aids tests, except that higher illumination levels, varying between 200 and 500 foot-lamberts of background illumination, were employed.

These experiments compared unstructured (i.e., untrained) visual search with two techniques of structuring the search method. The first technique used a vertical zigzag or saw-tooth method of searching the display. A second technique involved partitioning the complete display into three sections or "pages," and use of a horizontal zigzag search technique for each "page."

For the search experiments, the rate of target presentation ranged between a relatively high frequency, 18 targets in 20 minutes, to a relatively low rate of target presentation, six targets in approximately 25 minutes during the final or criterion test.

RESULTS

Optical Aids

The two experiments that compared low-power monocular aids with medium-power binocular systems indicated that observation with the low-power scope yielded later detection and a greater number of missed detections. The supplementary test conducted in neutral illumination indicated that detection with the low-power optics were no better than unaided observations. These results were attributed to the probable effect of optical aberrations and inefficient illumination transmission characteristics of the optical systems.

Search Patterns

The experiments on visual search techniques produced ambiguous results. Six out of nine observers detected targets more rapidly when using a vertical saw-tooth search technique than when using techniques of their own choice; however, three observers did less well when using the saw-tooth method. Further experimentation was conducted with 13 men who used unstructured search as well as other variations of the basic saw-tooth search pattern. Seven men performed worse when using the saw-tooth technique, four did better, and two did not change their performance levels.

Three experiments evaluated a horizontal searching method that consisted of partitioning the overall display into three sectors or "pages" and "reading" each page with a horizontal zigzag pattern of eye movements. One experiment compared this structured technique with unstructured search in terms of detection latency for targets of different altitudes and horizontal locations. The structured search produced more uniform detection than was characteristic of unstructured search. Visual acuity was also found to affect detection times.

In two subsequent experiments, considerably more training on the horizontal partitioning and scanning was provided. In both experiments, the average detection time was shorter for the structured method than the unstructured technique, but the differences were not statistically significant. Visual acuity was again found to influence detection times.

The results of these experiments coupled with informal observations by the research staff suggested that individuals with high visual acuity tend to "naturally" employ effective scanning procedures, while individuals with average or poor visual acuity tend to benefit from visual search training.

CONCLUSIONS

The most general conclusion that can be drawn on the basis of the research reported here is that the greatest facilitator of visual detection is a pair of "sharp" eyes. Although it cannot be categorically concluded that optical aids and systematic search patterns do not have beneficial effects upon detection time, the studies reported here certainly indicate that it is not easy to improve unaided visual detection through either optical assists or training in systematic methods of searching for small targets. Rather, it would appear that fundamental characteristics of vision such as visual acuity and, possibly, the field of view are the major sources of variance in determining the time required to acquire visual targets.

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Attempts to Improve Visual Detection Through Use of Search Patterns and Optical Aids

Chapter 1

PREVIOUS RESEARCH

OPTICAL AIDS

A number of experiments and field studies have been conducted under Work Unit SKYFIRE to obtain human performance data concerning the capabilities of human observers to detect low-flying aircraft. These studies were conducted at the request of the U.S. Army Combat Developments Command Air Defense Agency (USACDCADA) in support of continuing military requirements for air defense weapons capable of engaging low-flying, high-performance aircraft. A salient characteristic of such air defense weapons is that they are man-ascendant, in that they depend upon the human operator to detect, recognize, and determine when an aircraft is within the performance capabilities of the weapon.

In 1965, Wright (1) conducted field studies in the desert area north of El Paso, Texas, on the detection of low-flying, high-performance aircraft, such as the F-100 and the F-4C. Approximately 2,500 visual detection observations were made during this field test. Wright found that the average detection occurred at an observer-to-aircraft distance of approximately 10,000 meters, and this distance did not vary if the individual made observations unaided or with the use of 6X30 binoculars. In 1965, additional testing of detection performance was done at a site north of Las Vegas, Nevada, and reported by Frederickson, Follettie, and Baldwin (2). This testing used B-52 bomber and F-4C attack aircraft for targets. The F-4C aircraft flew a course originating beyond a far distant horizon. For these aircraft, the average detection range for unaided vision occurred at approximately 12,000 meters, and this distance was not increased by the use of 6X30 binoculars. Additional testing with the F-4C aircraft, which appeared from a distant horizon (mask) of about 24 kilometers, compared 6X30 and 7X50 binoculars, and again there was no difference in the mean detection range between the two types of optics. For both optical systems, the average detection occurred when the aircraft was 12.7-12.8 kilometers away.

These earlier tests, however, employed moderate-power optical aids, which have relatively limited fields of view. Interest was expressed by the USACDC in the potential effectiveness of low-power optical aids such as 1 1/2 to 3 power. There was particular interest in possibly using low-power optical aids for initial detection and, through zooming or automatic magnification, higher-power aids for aircraft recognition and identification.

The tests and experiments described in Chapter 2 of this report were conducted to evaluate low-power versus moderate-power optical aids.

SEARCH PATTERNS

Considerable research and operational analysis has been conducted on the design of optimum techniques for air-to-water or air-to-ground search (3). Research results on techniques for searching close-in displays such as radar indicators, situation displays, and maps are also available.

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However, although substantial work has been done in operations research to develop models of visual detection of aircraft, there has been essentially no empirical research concerning methods of scanning the sky by a ground observer. A review of the research literature in this area yielded only one relevant study, which was conducted by Craik and reported by Clark in 1943 (4). Craik extrapolated from research concerning the detection of stationary targets from moving aircraft. Based upon his extrapolations, he concluded that the best scanning routine for a ground observer was to sweep at a single elevation above the horizon or skyline at as fast a speed as the spotter could conveniently maintain (e.g., 10-20 degrees per second). In spite of the obvious significance of this problem area, apparently no additional research on the detection of aerial targets from the ground has been conducted since World War II.

The tests and experiments described in Chapter 3 were conducted to explore effects of search pattern techniques and training.

Chapter 2

OPTICAL AIDS FOR VISUAL DETECTION

DESCRIPTION OF TEST FACILITY

A comparison of optical aids was conducted in an indoor test facility designed to simulate a ground-to-air search situation. The test required observers to detect small black spheres or beads that were presented in front of a white screen. The test facility is pictured in Figure 1.

Indoor Test Facility

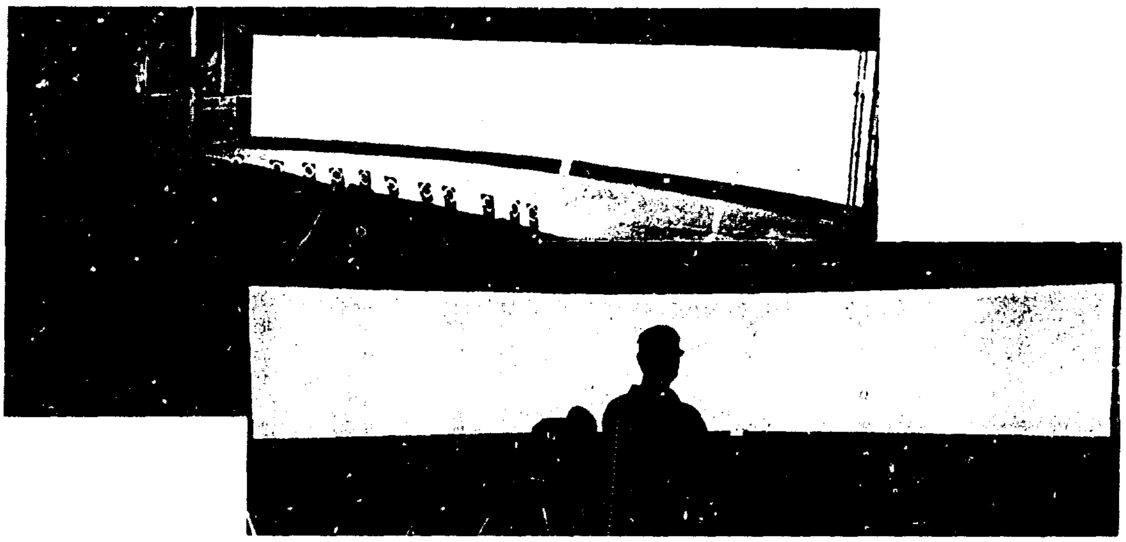

Figure 1

The observers were seated 12.2 meters (about 40 feet) from the screen. From the observer's location, the background screen subtended 1,082 mils horizontally and 205 mils vertically. At 17 horizontal locations, the targets could be elevated by invisible, monofilament lines from behind an occluding footboard.

Since the illuminating floodlights were positioned on the floor in front of the screen, the luminance of the background ranged from 45 foot-lamberts at the top to 80 foot-lamberts at the bottom of the screen. These luminance levels fall between those that characterize the sky luminance for a "very dark day" (10 foot-lamberts) and for an "overcast day" (100 foot-lamberts) as described by Middleton (5).

During the testing, equal numbers of targets were presented at low, medium, and high altitudes, and equal numbers of these were shown in the central horizontal sector (middle 50%) and the two peripheral sectors. One-half the target spheres had a diameter

of 3.2 millimeters; the remaining targets were 4.8 millimeters in diameter. When viewed from 12.2 meters, these targets subtended visual angles of 31 and 54 seconds, respectively. The geometry of the test facility, when using the 3.2-millimeter target, presented a visual area approximately equal to that which an MIG-21 with a 15° climb and a 10° heading would present at a range of about 13,800 meters.

Two tests were conducted using this test facility for the comparison of visual aids.

TEST NO. 1: COMPARISON OF FOUR OPTICAL AIDS

Test No. 1 involved a comparison of four visual aids:

(1) A U.S. Government-Issue (GI) 7X50 binocular manufactured by a leading optical company in the United States.

(2) A 2 1/2 to 8X35 zoom scope made in Japan. This zoom scope had a monocular objective and two "live" or functional eyepieces. It was locked at 2 1/2 power for this testing.

(3) A second GI 7X50 binocular modified ("degraded") through the use of neutral density filters to reduce the amount of luminance transmitted to the eye. The resulting amount of luminance reaching the eye approximated that of the zoom scope.

(4) An inexpensive 7X35 wide-angle binocular, also made in Japan.

Twenty observers participated in Test No. 1. Five observers were randomly assigned to each of the four optical aids. The observers ranged in age from 19 to 37 years, with a mean age of 23. Only seven of these men had moderate to extensive experience with binoculars or other spotting devices.

At the beginning of the test session, each observer was given instructions in adjusting the interpupillary distance between the eyepieces, and the focus control. The latter adjustment was accomplished primarily by viewing an optical resolution grid, supplemented by viewing a sample of the small target sphere. Both the resolution grid and the sample target were viewed from a distance of 12 meters.

The testing session for each observer extended over a one-hour period. During the one-hour watch, 12 targets were elevated at random places on the screen and at random time intervals The intertarget time intervals varied between 2 minutes, 15 seconds and 8 minutes, 45 seconds. No warning was provided concerning the time or place of appearance of a target.

The average acquisition time for each optical aid is presented in Table 1, along with the variance of the acquisition times. The means are the average of 60 observations for each optical system.

Table 1

Acquisition Times for Four Optical Aids

Optic	Mean (seconds)	Variance (seconds)
7X50 standard	30	791
2 1/2 X zoom scope	160	59,300
7X50 degraded	40	1,909
7X35 wide angle	50	6,881

Since it was apparent that the variances were not homogeneous and the distributions of the acquisition times were skewed, further analysis of the acquisition time scores appeared inappropriate. To reduce the heterogeneity and skewness, the acquisition times scores were transformed to logarithms of acquisition time (LAT). All subsequent analyses were performed on the transformed scores.

The LAT scores were subject to analysis of variance procedures using a split-plot factorial design as described by Kirk (6). This analysis involved four fixed factors and one random factor—the observers. The four fixed factors are (a) optical aid—four levels; (b) location of target on screen—central, 50% and non-central, 50%; (c) target size—small or large; and (d) target altitude—high, medium, or low. The analysis of variance permitted an evaluation of the magnitude of the effects of each factor plus the simple and compound interactions of all combinations of the fixed effects. The summary for this analysis of variance is given in Table 2.

The analysis showed the following statistically significant effects (i.e., $p \leq .05$):

(1) Optical aids: $F = 8.88$; $df = 3, 16$.
(2) Target size: $F = 28.62$; $df = 1, 16$.
(3) Interaction of target size and optics: $F = 3.50$; $df = 1, 16$.
(4) Target altitude: $F = 3.79$; $df = 2, 32$.

Table 2

Analysis of Variance for Comparison of 2½- and 7-Power Optics

Source	*df*	MS	*F*	*p*
Between Subjects				
Optics (A)	3	28,329	8.88	<.005
Error-A	16	3,192		
Within Subjects				
Target Location (B)	1	1,052	<1	
AB	3	265	<1	
Error-B	16	1,445		
Target Size (C)	1	50,925	28.62	<.001
AC	3	6,234	3.50	<.05
Error-C	16	1,779		
Target Altitude (D)	2	10,213	3.79	<.05
AD	6	4,142	1.54	NS
Error-D	32	2,692		
BC	1	3,713	2.23	NS
ABC	3	3,629	2.18	NS
Error-BC	16	1,664		
BD	2	4,522	2.93	<.10
ABD	6	906	<1	
Error-BD	32	1,545		
CD	2	502	<1	
ACD	6	2,624	1.36	NS
Error-CD	32	1,922		
BCD	2	583	<1	
ABCD	6	1,583	1.29	NS
Error-BCD	32	1,223		

The differences between the pairs of average scores for the optics were evaluated using Tukey's procedure (7). In each instance, the 2 1/2-power scope was significantly different (poorer) from each of the other optical aids. The differences among the three other aids, however, were not statistically significant.

The average amount of time required to detect the small targets was 107 seconds, whereas an average of 34 seconds elapsed before the large targets were acquired.

The interaction of optical aid and target size was attributed to a relatively larger amount of time required to detect the small targets when using the 2 1/2-power aid.

The effect of target altitude was manifested by a relatively shorter acquisition time for targets located at medium altitudes than for targets at either high or low altitudes.

TEST NO. 2: COMPARISON OF TWO OPTICAL AIDS

Test No. 2 compared the GI 7X50 binocular (not degraded) and a monocular zoom sighting system of 1.5- to 12-power manufactured in the United States. This optical system consisted of the basic unit of the XM 76, anti-oscillation sighting system. For the purpose of this test, the zoom optic was locked at approximately 3X.

Sixteen observers participated in the test with each observer using each optic for one-half hour. The observers ranged in age from 18 to 24 years with a mean age of 20.6 years. Eleven observers had moderate to extensive experience using binoculars during the previous year. The order of using the two optical aids was randomized for each observer, but an equal number of men first used the 7X50 or the 3X optic.

For this test, the original one-hour target presentation program was divided to provide two one-half hour programs, Form A and Form B. Equal numbers of observers were given the two test forms for each optical system. The design, therefore, permitted an evaluation of the following fixed effects: (a) optical aid, 7X50 versus 3X; (b) test form, A versus B; (c) order, first optic used versus second optic used; (d) all interactions of these three main effects.

Early in the course of conducting this test, it was found that many of the targets had not been detected by the end of the half-hour period when the observer used the 3-power scope. When the 7X50 optical aid was used, only 1% of the targets had acquisition times exceeding 300 seconds. In contrast, 44% of the acquisition times either exceeded 300 seconds or the targets were never seen with the 3X scope. Consequently, to permit analysis of the data, all missed targets and all acquisition times exceeding five minutes were assigned an arbitrary detection time of 300 seconds.

The mean acquisition time for the 7X50 binocular was 31 seconds, whereas the mean acquisition time for the 3X scope was 176 seconds. The average score for the 3X scope obviously is an underestimate of the true detection time, since the maximum acquisition delay was limited to 300 seconds.

The acquisition time scores were transformed to logarithms (LAT) and were analyzed using a Lindquist Type IV mixed analysis of variance (8). For this analysis, the mean LAT for the six target presentations and each test form for each subject was computed, and these mean LAT scores were evaluated. The mean LAT was used in this test evaluation rather than the individual trials in order to reduce the variability of individual differences resulting from the small number of trials comprising each half-hour test.

The summary of the analysis of variance is shown in Table 3. This analysis revealed the following statistically significant effects:

(1) Optics: $F = 43.00$; $df = 1, 12$.

(2) Order: $F = 5.41$; $df = 1, 12$.

Table 3

Analysis of Variance for Comparison of 3- and 7-Power Optics

Source	*df*	MS	*F*	*p*
Between Subjects				
Order (C)	1	1,568	5.41	<.05
Optics x Test Forms (AB)	1	2	<1	
Optics x Test Forms x Order (ABC)	1	3	<1	
Error	12	290		
Within Subjects				
Optics (A)	1	30,752	43.00	<.001
Test Forms (B)	1	171	<1	
Optics x Order (AC)	1	91	<1	
Test Forms x Order (BC)	1	265	<1	
Error	12	715		

The extremely poor performance of the observers when using the 3X scope is puzzling. Since this scope has an objective lens with a diameter of 47 millimeters, its light-gathering capability should have been quite high. However, the mean acquisition time for the 3X scope was much greater than for any of the other optical systems that were evaluated in both tests.

It is relevant that many of the observers informally made adverse comments about the effectiveness of the 3X scope. The most frequent complaints concerned eye fatigue, particularly as the half-hour test period progressed. These self-reports were supported by measurements made of the cumulative amount of time each observer removed the optic from his eyes (rest time) during each half-hour test period. The median total rest time for the 7X50 binocular was 70.5 seconds, and for the 3X scope 140 seconds.

During informal searches with the 3X scope, research staff members reported that a target was essentially not visible if its position in the field of view of the optic deviated from the optical axis by more than 5-10°. More systematic measurement of this phenomena was not conducted.

The possibility existed that this scope was uniquely ineffective at the relatively low luminance level used in this test because of the large number of lenses required to provide its zoom characteristics. The large number of lenses both reduced the light transmitted and increased image distortion. Additional tests were therefore conducted to evaluate its efficiency under higher illumination conditions. (Before these additional tests, the scope was returned to the manufacturer to be examined for possibie damage that might account for the poor performances.)

The supplementary tests for the zoom scope were conducted outdoors, and involved a comparison of the zoom optic versus unaided visual detection. The apparatus used for the outdoor testing consisted of a vertical frame 2.8 meters wide and 3.3 meters high. Between the horizontal members of the frame were suspended three monofilament lines, each of which carried a black bead approximately 3.2 millimeters in diameter. The three lines were about 0.8 meter from each other. A clear sky background was used during these tests.

Sky reflectance was 2,125 foot-lamberts as measured by a spot photometer, and target-to-background contrast was 46%. Two staff members served as observers for 15 trials under each viewing condition—unaided vision and with the 3X optic. The mean acquisition time for each observer under each condition is presented.

Mean	Observer A	Observer B
3X	24.2 secs.	19.1 secs.
Unaided	24.3 secs.	17.2 secs.

Based upon these results, there was no indication that the zoom optic at low power facilitated visual detection under bright daylight conditions. Since these preliminary results suggest that unaided observation was as effective as aided viewing, it was concluded that initiation of more extensive testing of the zoom scope was not warranted.

CONCLUSIONS CONCERNING OPTICAL AIDS

The results of these tests support the extensive full-scale detection data reported by Wright. In Wright's testing, unaided visual detection was compared with aided detection using 6X30 binoculars (1). He found no general tendency for aided observations to increase detection ability. Similar results subsequently were obtained by Frederickson, Follettie, and Baldwin, who hypothesized that the reduced field of view of optical aids adversely influenced detection. The laboratory experiments reported here further suggest that the optical aberrations and light transmission losses that were characteristic of the low-power monocular systems tested reduced the discriminability of the targets, and thereby adversely influenced detection.

Based upon these results, it was concluded that visual aids of low, as well as medium, power do not facilitate detection in ground-to-air search situations. It was, therefore, decided that additional research on optical aids would not be conducted. Instead, the research effort would concentrate on evaluations of alternative techniques of visual search.

Chapter 3

PATTERNS OF VISUAL SEARCH

DESCRIPTION OF TEST FACILITY

Four experiments were conducted during January-April 1972 on alternative techniques for searching large displays. The indoor test facility described in the previous chapter was used for these experiments.

The test conditions were modified in three important characteristics. First, all observations were made unaided and from an observer-to-screen distance of 11 meters. Second, only the small size targets, 3.2 millimeters, were used for these tests. Third, the illumination of the screen was increased substantially. At the horizontal periphery of the screen, the average reflected light was 200 foot-lamberts; for all other portions of the screen, the luminance level was approximately 500 foot-lamberts. These relatively high levels of illumination were obtained through the use of 12 1,000-watt photo-flood lamps.

SAW-TOOTH SEARCH PATTERN (VERTICAL ZIGZAG)

In January 1972, a pilot experiment was conducted that compared target acquisition times under unstructured and structured search conditions. For the unstructured condition, the observers were given no information concerning a technique of search, and were free to search for the targets using any pattern or technique they desired. Under the structured condition, the observers were *requested* to use a vertical saw-tooth method of scanning the target presentation area. Markers were placed along the top and bottom of the screen as a visual aid for the saw-tooth pattern.

The surveillance period extended about 30 minutes, during which time six targets were presented at random places and at random time intervals. The performance measure was acquisition time—the time elapsing between presentation of the target and its detection. Each target was presented for a maximum of 300 seconds; undetected targets were assigned an acquisition time of 300 seconds.

Twelve observers, all U.S. Army enlisted men, were tested in the unstructured condition on the first day of the two-day test program. Nine of these men were available for retesting under the structured condition on the second day. The mean acquisition time for six targets under each condition is shown in Table 4 for each of the nine observers.

It is apparent that six of the nine observers detected targets more rapidly under the structured condition, and three observers did not detect targets as rapidly as when viewing the screen in the unstructured manner. The average difference in acquisition times over all observations was 29 seconds less under the structured condition, although this difference was not statistically reliable.

The possibility existed that the training aid provided to guide the saw-tooth pattern may have interfered with searching the target presentation area. The training aid consisted of numerals alternately positioned at the bottom and the top of the screen, and the observers were instructed to pace their eye movements by silently counting "1000 - 1, 1000 - 2," and so on to "1000 - 18." Although the men were told not to fixate the

Table 4

Acquisition Times for Vertical Zigzag Search Pattern
(seconds)

Observer Number	Unstructured	Structured Vertical Saw Tooth	Difference
1	39	15	24
2	80	88	–8
3	94	170	–76
4	84	54	30
5	170	28	142
6	192	143	49
7	219	156	63
8	40	113	–73
9	219	112	107

numerals after the first few scans, some observers may have been unable to follow these instructions. If so, their attention may have been on the numerals rather than on the segments of the screen. Since the results of the pilot experiment did suggest that the saw-tooth pattern may be effective for visual search, more extensive testing was undertaken.

Further experimentation concerning the saw-tooth search method was planned to test the target acquisition performance of 20 observers under both unstructured and structured search. The observers first would be tested under the "free" search method; that is, they would be given no instruction concerning the method to be used. Subsequently, these observers would be retested after receiving instruction concerning the saw-tooth or vertical zigzag method.

When the testing involved the saw-tooth method, 18 eye markers or eye movement guides were fastened to the top and bottom of the screen. These were intended to serve as aids for guiding the vertical zigzag of eye and head movements. To reduce the possiblity of fixating on the eye movement guides, the left-to-right zigzag was marked by black circles, positioned alternately at the top and bottom of the screen. The right-to-left zigzag was marked by triangles, positioned in similar fashion.

Each testing session for each observer consisted of 18 targets that were presented at random times and locations during a 30-minute time period. Six men were tested on the first day of the experimental program, and they used both the free and the saw-tooth methods. Four of these observers performed less well when using the saw-tooth method than when using their own technique. When averaged over all six observers, the mean acquisition time was 21 seconds greater for the saw-tooth technique.

Since the number of eye motion markers was relatively small for searching such a wide sector, it was decided to increase the fineness of the saw-tooth by increasing the number of eye motion guides from 18 to 36. After this change in the training procedure, three men were tested and then retested during the morning of the second day using the fine saw-tooth method. All other experimental conditions were like those used on the first day. The results for the second morning's testing yielded all possible results: One man did worse with the fine saw-tooth method, one remained the same as when using the free method, and one man did better with the saw-tooth.

Since the results were still ambiguous, it was decided to reduce the frequency of target appearance from 18 to 6 targets per 30-minute period. This change resulted from an inference concerning the effect of additional job structuring upon performance in

vigilance (monitoring) tasks. Previous research (9) has shown that attention level is directly related to signal, or target, frequency. It was therefore conjectured that the benefits of additional job structuring, such as the use of systematic search techniques, may be more apparent when signal frequency and attention level are low than when they are high.

Four men were tested the afternoon of the second day, using the fine saw-tooth technique with the test program of six targets per 30-minutes. Two of these men did better with the saw-tooth method than with the unstructured search, one performed equally well under both conditions, and one man did worse when using the saw-tooth.

At the end of the second day, of the 13 men tested with the saw-tooth technique, seven had performed less well using this method, four did better, and two did not change. On the basis of these results, it was concluded that the saw-tooth method was not an effective technique for searching for near-threshold targets. It was conjectured that the eye movements involved in the vertical saw-tooth were unnatural in comparison with the type of eye movements employed by Caucasians most frequently—that is, when reading.

HORIZONTAL ZIGZAG PATTERN

The next experiment made use of a horizontal zigzag method of scanning display patterned after the type of eye movements involved in scanning the printed page or outdoor billboards. After observers had been tested in the free or unstructured condition, they were instructed and tested in the horizontal zigzag method, or structured technique.

For the structured technique, the screen was partitioned into three sectors or "pages" of approximately equal area by placing two vertical poles in front of the display (see Figure 2). On each pole were fastened four black, short strips of paper that served as horizontal eye movement guides for imaginary lines. The observers were told to begin searching the left sector by scanning, in turn, the four imaginary lines. Next they were to scan the center sector, and finally, the right sector. If the target had not yet been detected, they were to begin all over again on the left sector. The test program consisted

Partitioned Screen for Testing Under the Horizontal Structured Technique

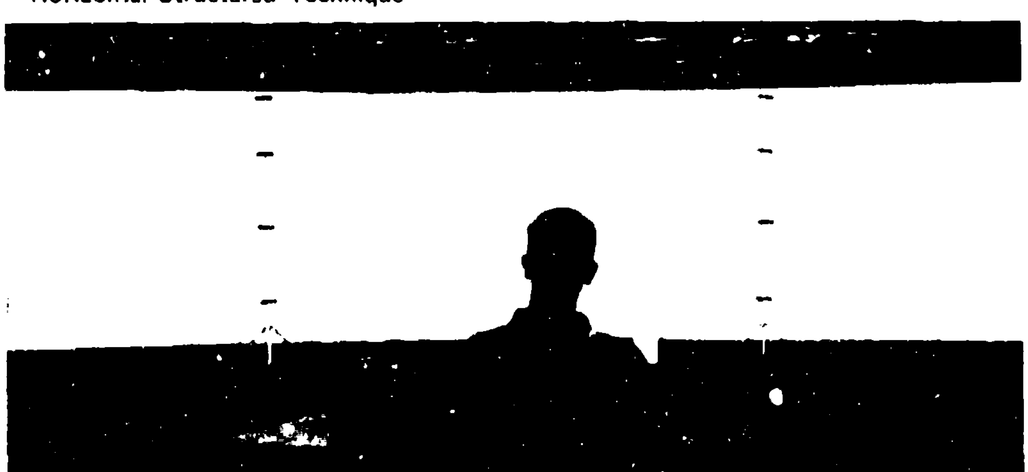

Figure 2

of 18 targets presented in a 30-minute period. Thirteen men were tested with the unstructured technique and then retested using the horizontal zigzag method.

The 18-target test had been designed so that equal numbers of targets appeared in each of nine areas of the background screen: high, middle, and low vertically; and right, center, and left horizontally. This design permitted evaluation of the acquisition times for all portions of the display.

The average target acquisition time for each of the nine screen areas was computed for each observer for each of the two tests—free and structured. Analysis of variance procedures were used to evaluate the data obtained. The acquisition time scores were transformed to their corresponding logarithms (LAT) to eliminate skewness in the frequency distributions of the scores. The summary of the analysis of variance is presented in Table 5.

Table 5

Analysis of Variance for Horizontal Zigzag Search Pattern

Variance Source	*df*	MS	F^a	*p*
Between Subjects (S)	12			
Within Subjects				
Search Technique (A)	1	4,746	4.25	.10
Error-A	12	1,115		
Horizontal Location (B)	2	5,749	3.21	.10
Error-B	24	1,787		
Target Altitude (C)	2	17,829	11.17	.001
Error-C	24	1,596		
Technique by Horizontal Location (AB)	2	2,426	1.68	NS
Error-AB	24	1,437		
Technique by Altitude (AC)	2	9,860	39.44	.001
Error-AC	24	250		
Location by Altitude (BC)	4	4,749	4.24	.01
Error-BC	48	1,120		
Technique by Location by Altitude (ABC)	4	2,072	1.36	NS
Error-ABC	48	1,519		

[a]Required Significance Levels

df	$F_{.05}$	$F_{.01}$
1.12	4.75	9.33
2.24	3.40	5.61
4.48	2.61	3.83

The analysis reveals several variance sources that were greater than chance expectations. Although the overall difference between search techniques was not significant at the .05 level, the interaction of search technique and target altitude was significant ($p<.001$).

In Table 6, the mean acquisition time (seconds) is given for targets at each altitude, for both the free and the structured methods. When free search was employed, the mean

Table 6

Acquisition Times for Three Target Altitudes for Horizontal Zigzag Search Pattern
(seconds)

Altitude	Free Search	Structured Search (Horizontal Zigzag)
High	39.8	28.8
Medium	26.9	34.0
Low	76.2	34.8

acquisition times varied greatly among the target altitudes. In contrast, with the structured search method there was much less variability in the mean acquisition times for the different target altitudes.

There was also a significant interaction between target horizontal location and altitude. The average acquisition time (seconds) for each of the nine areas of the background screen is shown in Table 7. These results suggest that the observers tended to bias their scanning toward the middle and upper left, the middle center, and the upper right of the screen. That is, it is inferred that the observers tended to employ a U-shaped scan.[1] Similar scanning patterns were suggested by the results of the previous SKYFIRE study, which evaluated optical aids for detection.

Table 7

Acquisition Times for Six Target Locations for Horizontal Zigzag Search Pattern
(seconds)

Target Altitude	Target Location		
	Left	Center	Right
High	26.2	41.4	34.7
Middle	17.7	16.9	51.2
Low	64.5	38.2	64.6

An alternative hypothesis was that the systematic variations in the luminance of the background screen might have affected the detectability of the targets. To examine this possibility, the brightness of the background screen in the vicinity of each target was measured by a spot photometer. The correlation between these measurements and the mean acquisition time for each target over all observers was computed. When free search was employed, the product moment correlation was −.40. When structured search was involved, the correlation was −.29. Neither correlation coefficient was statistically reliable. Although screen brightness varied between 200 and 500 foot-lamberts, the range of variation was not reliably correlated with variations in the acquisition times.

[1] In the absence of instrumentation for directly recording eye movements over time, it was not possible to attempt to monitor the actual scanning patterns used by observers. Although photographic techniques for recording eye and head movements have been devised, Alpern recently concluded that they often produce invalid records of the change of fixation points over time (10).

Variation in acquisition time was, however, correlated with the observer's visual acuity. Far visual acuity was determined for each eye by testing the men with the Armed Forces Vision Tester. The average far visual acuity for both eyes was determined, and the correlation between this measure and log mean acquisition time for each observer was computed. When free search was used, the correlation was .51; this was not statistically reliable. When structured search was involved, a correlation of .65 was obtained, which was statistically reliable ($p < .01$).

These results suggested that when free search was involved, the difference between the acquisition times of various observers was a result of chance or random variations in scanning methods—that is, how often the observers were scanning the correct area of the screen when the target was presented. However, when structured search was used, all observers were using comparable scanning methods, and the variation in acquisition times was affected by differences in the visual acuity of the observers. Since the visual acuity of the 13 observers only varied between 20/13 and 20/22, it is highly probable that an even stronger correlation would exist in the general population of military personnel, because the variation in visual acuity is much greater in the general population than was characteristic of the sample used in this test.

The result of this experiment indicated that structuring the visual search technique did assist detection of high and low targets. The results for the saw-tooth method, however, indicated that just attempting to structure or systematize search patterns, by any method, does not always facilitate detection.

At the conclusion of this experimentation, it was realized that additional research would be necessary before a final method of patterning visual search could be devised. Some observers had not performed better when using the horizontal zigzag method; also, it was not known whether observers would continue to use the structured search method in the absence of the scanning aids used during the experiments to partition the search sector and to guide eye movements.

TRAINING IN HORIZONTAL ZIGZAG PATTERNS

Additional research concerning the horizontal zigzag or structured method of search was conducted in March 1972. The previous experiments had not included any formal training period in the search patterns to be used. Brief instructions had been given concerning the use of the eye markers prior to the test concerning structured search, but no practice in using this method had been provided in the initial research on this method. In the March experiment, formal training was included in the research program.

TRAINING RESULTS

Each of 20 observers was first tested in the free or unstructured method. This test consisted of 12 targets presented at random times during a 20-minute interval. Following a rest period, each observer returned to the experimental area and was given training with the horizontal zigzag method.

For the training period, 18 targets were presented successively as rapidly as the observer located them. For the first nine target presentations, the two vertical poles were placed in front of the screen. At the end of the first nine targets, the poles were removed and were replaced by shorter markers simulating fence posts or stakes. During training, the observers were told how rapidly they were finding the targets. They were also given assistance in locating targets if the elapsed acquisition time exceeded 30 seconds.

Following another rest period of approximately one-half hour, each observer returned for the final test involving the structured or horizontal zigzag method. For this final test, the short markers were present to aid in partitioning the display into three sectors. A six-target program was used in which these targets appeared in about a 25-minute interval at random times and places on the screen. No information concerning their performance levels was provided the observers during the final test.

The average acquisition time for the unstructured or free search test was 41.6 seconds. The average acquisition time for the horizontal zigzag method was 37.7 seconds. This difference was not statistically reliable. Of the 20 observers, 13 performed better with the structured method, and seven performed worse.

VISUAL ACUITY

A measure of far visual acuity was obtained on the Armed Forces Vision Tester. The visual acuity of this sample of men ranged between 20/20 and 20/14.

The correlation between visual acuity and acquisition time was computed for both unstructured and structured test situations. For the unstructured test, the correlation was 0.62, which was statistically reliable. For the structured test, however, the correlation was 0.39, which was not statistically reliable. Results for the acuity measures obtained in this experiment, therefore, were at variance with those obtained during the initial experiment with the horizontal zigzag.

FIELD OF VIEW

It was hypothesized that the width of an individual's field of view would influence the probability that he would detect a target. That is, those individuals with a wide field of view would be able to apprehend a larger area of the display with a single glimpse or a single look.

Gross estimates of the horizontal field of view of the subjects were made using the apparatus shown in Figure 3. The apparatus consisted of a horizontal board containing a circular fixation point at its center. A movable sphere 3.2 millimeters in diameter could be positioned to either side of the fixation point to a distance of .9 meter on each side. Below and in front of the stationary target board was a movable shutter that contained a fixation line in the same vertical plane as the fixation point on the target board. Each observer was instructed to fixate the line on the shutter while it was elevated before a trial. While the target board was occluded by the shutter, the experimenter placed the 3.2-millimeter target at some arbitrary point on the target panel. The shutter was then lowered, and the observer was instructed to fixate on the fixation dot and to tell the experimenter if he saw the target sphere.

Trials with this apparatus continued, using binocular vision, until the observer obtained four of five affirmative trials at a constant peripheral distance. Field-of-view measures were obtained for both the right and the left sides of the target panel. The field-of-view measures were taken over two observing distances—9 and 11 meters.

These field-of-view measures were then correlated with acquisition time and visual acuity. The correlation between the 9- and 11-meter measures of field of view was .55, which was statistically significant ($p<.01$). Neither field-of-view measure, however, was reliably correlated with either acquisition time or visual acuity.

Field-of-View Apparatus

Figure 3

THE FINAL EXPERIMENT

Although the previous experiment had produced equivocal results, it was decided to conduct one more experimental comparison of free versus structured search methods. Eighty observers participated in the final experiment.

COMPARISON OF METHODS

Half the observers were given practice using whatever technique of search they chose, and the other half of the observers were trained using the horizontal zigzag method. This training was like that used in the March 1972 experiment. The training consisted of 18 target presentations, and feedback (knowledge of results) was provided to both groups for each training trial.

After a rest interval of 30-40 minutes, each observer returned to the display room for the criterion test. For those individuals who had been trained in the horizontal zigzag method, the short markers were positioned in front of the screen as they had been during the last half of their training period. There were no aids for those individuals tested under the free search condition, with the exception of one sample target, which was positioned at the bottom center of the display. This target was used as an aid for maintaining visual accommodation. It was present during the criterion tests for both groups of observers. The criterion test consisted of six targets presented in a 25-minute period. No knowledge of results was provided during this test.

The mean detection time for the free-search condition was 50.3 seconds, with a standard deviation of 34.1 seconds. The mean detection time for the structured search group was 38.0 seconds, with a standard deviation of 21.5 seconds. The two mean detection times were evaluated by means of a t-test. The obtained t was 1.74, which, for 78 degrees of freedom, was not significant.

On the assumption that the distributions of visual acuity of the observers may not have been the same for both treatment conditions, the detection time data were reanalyzed by means of covariance, using visual acuity as the predictor measure. The obtained F-ratio was 0.32. This result, in combination with the result of the t-test analysis, indicated that the differences that had been obtained between the two search methods could be attributed to unequal distributions of visual acuity, rather than gains associated with structured search techniques.

VISUAL ACUITY

The correlation between the logarithm of detection time and visual acuity was .58 for the free search condition and .42 for the structured search condition. Both correlations were statistically significant ($p<.01$).

FIELD OF VIEW

The field-of-view measurements were also taken for each subject for an observing distance of nine meters. The correlation between the logarithm of detection time and the field-of-view measure was −.35 for the free search condition and −.08 for the structured search. The correlation for the free search condition was statistically reliable ($p<.05$).

These results suggest that for the free search condition, those individuals with the larger fields of view were able to apprehend larger portions of the screen at a single look. As a result, their detection times tended to be shorter. In contrast, since the number of looks per sector tended to be equalized for all observers using the structured search condition, there was no correlation between field of view and detection time.

CONCLUSIONS CONCERNING SEARCH PATTERNS

When evaluated collectively, the results of the four experiments concerning techniques of structuring visual search do not indicate that the vertical zigzag and horizontal zigzag techniques produce more rapid detections of near-threshold targets. The first experiment conducted with the horizontal zigzag method did suggest that the structured method tended to equate the observing responses for different portions of the overall display, consequently targets tended to be detected earlier under the structured method for those portions of the display that probably were not scanned as frequently when using a free method of search. Since the test programs used to evaluate structured search training in subsequent experiments did not permit evaluation of interactions with target location, no additional evidence was obtained to support the hypothesis concerning interactions with target altitude. The four experiments do indicate, however, that structuring search does not produce a profound effect upon acquisition time.

The significance of visual acuity as a determiner of target acquisition time was clearly indicated in the last two experiments conducted. Data concerning visual acuity were not obtained during the first two experiments. Although it should be fairly obvious

that individuals with "keen" vision should do a better job in detecting hard-to-see objects, the significance of this relationship may often be overlooked in practical target detection situations.

The possible importance of field of view as a determiner of detection time also should not be overlooked in future research done concerning target detection. The instrumentation available to estimate field of view during this research was relatively crude in comparison to measurement equipment that has been used in more rigorous studies of this characteristic of vision (11). It is believed that additional research concerning the relationship between field of view and the observer-to-target distance should be accomplished. A number of the target detection models developed in the operations research field assume a detection lobe for a single glimpse that varies in width as a function of the observing distance. Apparently there is an absence of empirical data concerning the actual width of the field of view as a function of observing distance.

Chapter 4

GENERAL CONCLUSIONS

The most general conclusion that can be drawn on the basis of the research reported here is that the greatest facilitator of visual detection is a pair of "sharp" eyes. Although it cannot categorically be concluded that optical aids and systematic search do not have beneficial effects upon the time required to detect small objects, these studies certainly have indicated that it is not easy to improve unaided visual detection through either optical assists or training in systematic methods of searching for near-threshold targets.

The most fundamental properties characteristic of vision such as visual acuity and, possibly, field of view are obviously potent sources of variance in determining time required to acquire visual targets. It would appear that additional research would be beneficial to further investigate the effects of field of view upon detection, particularly with reference to determining changes in field of view as a function of ground observer to aerial target range. Activation of earlier research of the type conducted by Low (12) on training the field of view also appears to be desirable.

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1 CO HQS BN USAFAC & FT SILL ATTN S3
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3 CO + DIR NAV TNG DEVICE CTR ORLANDO ATTN TECH LIB
1 CO FLT ANTI-AIR WARFARE TNG SAN DIEGO
2 US FLT AAW TNG CTR DAM NECK VA
2 CO FLT NG CTR NAV BASE NEWPORT
1 COR FLT TNG GP NAV BASE CHARLESTON
2 CO US FLT TNG CTR NORFOLK
1 CO FLEET TNG CTR US NAV STA SAN DIEGO
1 CLIN PSYCHOL MENTAL HYGIENE UNIT US NAV ACAD ANNAPOLIS
1 PRES NAV WAR COLL NEWPORT ATTN MAHAN LIB
3 CO SERV SCH COMD NAV TNG CTR SAN DIEGO
3 CO NAV GUIDED MSL SCH DAM NECK VA BEACH
1 CO FLT ANTI-SUB WARFARE SCH SAN DIEGO
1 CHF OF NAVL RSCH PERS & TNG BR (CODE 458) ARL VA
1 CHF OF NAV RES ATTN DIR PSYCHOL SCI DIV CODE 450
1 CHF OF NAV RES ATTN HEAD GP PSYCHOL BR CODE 452
1 DIR US NAV RES LAB ATTN CODE 5120
1 DIR NAVAL RSCH LAB ATTN LIB CODE 2029 WASH DC
1 CHF OF NAV AIR TNG TNG RES DEPT NAV AIR STA PENSACOLA
1 CO NAV SCH OF AVN MED NAV AVN MED CTR PENSACOLA
1 LIB NAV MED RES LAB NAV SUB BASE GROTON
1 CO MED FLD RES LAB CAMP LEJEUNE
1 CDR NAV MSL CTR POINT MUGU CALIF ATTN TECH LIB CODE 3022
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1 HQ MARINE CORPS ATTN AX
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1 DIR MARINE CORPS INST ATTN EVAL UNIT
1 CG(G5) III MARINE AMPHIBIOUS FORCE MAC FPO SAN FRAN 96602
1 US MARINE CORPS HQS HIST REF LIB ATTN MRS JADOT
1 DIR OPS EVAL GRP OFF OF CHF OF NAV OPS OP03EG
2 COMDT PTP COAST GUARD HQ
1 CHF OFCR PERS RES + REVIEW BR COAST GUARD HQ
1 CO US COAST GUARD TNG CTR GOVERNORS ISLAND NY
1 CO US COAST GUARD TNG CTR CAPE MAY NJ
1 CO US COAST GUARD TNG CTR & SUP CTR ALAMEDA CALIF
1 CO US COAST GUARD INST OKLA CITY OKLA
1 CO US COAST GUARD RES TNG CTR YORKTOWN VA
1 SUPT US COAST GUARD ACAD NEW LONDON CONN
1 TECH DIR TECH TNG DIV(HRD) AFHRL LOWRY AFB COLO
1 CHF SCI DIV DRCTE SCI + TECH DCS R+D HQ AIR FORCE AFRSTA
1 CHF ANAL DIV (AFPDPL (R) DIR OF PERSONNEL PLANNING HQS USAF
2 DPTY TIG USAF (AFIAS-GI) NORTON AFB
1 RADC RASH GRIFFISS AFB NY
2 CDR ELEC SYS DIV LG HANSCOM FLD ATTN ESMDA/STOP 36 MASS
2 SMAMA (SMACU-PERS RSCH) MCCLELLAN AFB
1 ATC ATXHQ RANDOLPH AFB
1 AFHRL/TT ATTN CAPT W S SELLMAN LOWRY AFB
1 HQ SAMSO (SMSIR) AF UNIT POST OFC LA AFS CALIF
2 MILIT TNG CTR OPF LACKLAND AFB
2 AFHRL (HRT) WRIGHT-PATTERSON AFB
1 AMD AMRH BROOKS AFB TEXAS
1 HQS ATC DCS/TECH TNG (ATTMS) RANDOLPH AFB
1 CDR ELEC SYS DIV LG HANSCOM FLD ATTN ESTI MASS
1 USAF SCH OF AEROSPACE MED ATTN AEROMED LIB BROOKS AFB
1 USAFA DIR OF THE LIB USAF ACAD COLO
1 DRCTE OF AEROSPACE SAFETY AFIAS-L DPTY IG NORTON AFB
1 6570TH PERS RES LAB PRA-4 AEROSPACE MED DIV LACKLAND AFB
1 TECH TNG CTR (LMTC/OP-1-LI) LOWRY AFB
2 CO HUMAN RESOURCES LAB BROOKS AFB
1 COMDT USAF SPEC OP SCH (TAC) EGLIN AFB
1 AFHRL (FT) WILLIAMS AFB ARIZ
1 PSYCHOBIOLOGY PROG NATL SCI FOUND
1 DIR NATL SCI FOUNDN WASHINGTON ATTN ASST DIR FOR SOC SCI
1 DIR NATL SECUR AGY FT GEO G MEADE ATTN TDL
1 DIR NATL SECUR AGY FT GEO G MEADE ATTN DIR OF TNG
3 CIA ATTN CRS/ADD STANDARD DIST
1 SYS EVAL DIV RES DIRECTORATE DOD-DCD PENTAGON
1 DEPT OF STATE BUR OF INTEL + RES EXTERNAL RES STAFF
3 US INFO AGY INT L PROCUREMENT LIB
1 SCI INFO EXCH WASHINGTON
2 CHF MGT & GEN TNG DIV TR 200 FAA WASH DC
1 BUR OF RES & ENGR US POST OFC DEPT ATTN CHF HUMAN FACTORS BR
1 EDUC MEDIA BR OE HEW ATTN T D CLEMENS
1 OFC OF INTERNATL TNG PLANNING & EVAL BR AID WASH DC
1 FAA MED LIB HQ 640 WASH DC
1 DEPT OF TRANS FAA ACQ SEC HQ 610A WASH DC
2 ERIC OF WASH DC
1 CONSOL FED LAW ENFORCEMENT TNG CTR WASH DC
2 SYS DEVEL CORP SANTA MONICA ATTN LIB
2 DUNLAP + ASSOC INC DARIEN ATTN LIB
2 RAC ATTN LIB MCLEAN VA
1 RAND CORP WASHINGTON ATTN LIB
1 DIR RAND CORP SANTA MONICA ATTN LIB
1 GP EFFECTIVENESS RSCH LAB U OF ILL DEPT OF PSYCHOL
2 ELECT PERS RSCH GP U OF SOUTHERN CALIF
1 COLUMBIA U ELEC RES LABS ATTN TECH EDITOR
1 MITRE CORP BEDFORD MASS ATTN LIB
1 HUMAN SCI RES INC MCLEAN VA
2 TECH INFO CTR ENGNR DATA SERV N AMER AVN INC COLUMBUS O
1 CHRYSLER CORP MSL DIV DETROIT ATTN TECH INFO CTR
1 AVCO CORP AVCO MSL SYS DIV ATTN RSCH LIB WILMINGTON MASS
3 CTR FOR RSCH IN SOCIAL SYS ATTN LIBN MD
1 RAYTHEON SERV CO ATTN LIBN BURLINGTON MASS
1 GEN DYNAMICS POMONA DIV ATTN LIB DIV CALIF
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1 SCI & TECH DIV IDA ARL VA
1 HUGHES AIRCRAFT COMPANY CULVER CITY CALIF
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1 EDITOR TNG RES ABSTR AMER SOC OF TNG DIRS U OF TENN
1 U OF CHICAGO DEPT OF SOC
3 CANADIAN JOINT STAFF OFC OF DEF RES MEMBER WASHINGTON
3 CANADIAN ARMY STAFF WASHINGTON ATTN GSO2 TNG
2 CANADIAN LIAISON OFCR ARMY ARMOR BD FT KNOX
1 GERMAN LIAISON OFCR ARMY AVN TEST BD FT RUCKER
2 OFC OF ARMED FORCES ATTACHE ROYAL SWEDISH EMBSY DC
3 AUSTRALIAN NAV ATTACHE EMBSY OF AUSTRALIA WASH DC
2 FRENCH ARMY LIAISON OFCR USAAVNC & FT RUCKER
1 BRITISH LIAISON OFCR ARMY AVN TEST BD FT RUCKER
1 OFC OF AIR ATTACHE AUSTRALIAN EMBSY ATTN: T.A. NAVGN WASH, D.C.
2 AUSTRALIAN ARMY ATTACHE EMBSY OF AUSTRALIA ATTN TECH CLK
2 DR R T DODD LRNING SYS LTD SURREY ENGLAND
1 MENNINGER FOUNDATION TOPEKA
1 AMER INSTS FOR RSCH SILVER SPRING
1 AMER INSTS FOR RSCH ATTN LIBN PA
1 GEN ELECTRIC CO SANTA BARBARA ATTN LIB
1 U OF GEORGIA DEPT OF PSYCHOL
1 AMER INST FOR RSCH ATTN LIB PALO ALTO CALIF
1 NORTRONICS DIV OF NORTHROP CORP ANAHEIM CALIF
1 OHIO STATE U SCH OF AVN
2 AIRCRAFT ARMAMENTS INC COCKEYSVILLE MD
1 AMER PSYCHOL ASSOC WASHINGTON ATTN PSYCHOL ABSTR
1 LIFE SCI INC HURST TEXAS ATTN W G MATHENY
1 AMER BEHAV SCI CALIF
1 NORTHWESTERN U DEPT OF INDSTR ENGNR
1 AEROSPACE SAFETY DIV U OF SOUTHERN CALIF LA
1 DR S ROSCOE ASSOC DIR FOR RSCH INST OF AVN U OF ILL
1 DR H SHOEMAKER DIR TNG RSCH GP NY
1 CHF PROCESSING DIV DUKE U LIB
1 U OF CALIF GEN LIB DOCU DEPT
1 FLORIDA STATE U LIB GIFTS + EXCH
1 PSYCHOL LIB HARVARD UNIV CAMBRIDGE
1 U OF ILL LIB SER DEPT
2 U OF KANSAS LIB PERIODICAL DEPT
1 U OF NEBRASKA LIBS ACQ DEPT
1 OHIO STATE U LIBS GIFT + EXCH DIV
1 PENNA STATE U PATTEE LIB DOCU DESK
1 PURDUE U LIBS PERIODICALS CHECKING FILES
1 STANFORD U LIBS DOCU LIB
1 LIBN U OF TEXAS
1 SYRACUSE U LIB SER DIV
1 SERIALS REC UNIV OF MINN MINNEAPOLIS
1 STATE U OF IOWA LIBS SER ACQ
1 NO CAROLINA STATE COLL DH HILL LIB
2 BOSTON U LIBS ACQ DIV
1 U OF MICH LIBS SER DIV
1 BROWN U LIB
1 COLUMBIA U LIBS DOCU ACQ
1 DIR JOINT U LIBS NASHVILLE
1 U OF DENVER MARY REED LIB
2 LIB GEO WASH UNIV ATTN SPEC COLL DEPT WASH DC
2 LIB OF CONGRESS CHF OF EXCH + GIFT DIV
1 U OF PGH DOCU LIBN
1 CATHOLIC U LIB EDUC & PSYCHOL LIB WASH DC
1 U OF KY MARGARET I KING LIB
1 SO ILL U ATTN LIBN SER DEPT
1 KANSAS STATE U FARRELL LIB
1 BRIGHAM YOUNG U LIB SER SECT
1 U OF LOUISVILLE LIB BELKNAP CAMPUS
1 GEORGETOWN U LIB SER DEPT WASH DC
1 LIBS COLO STATE U ATTN DOC LIBN FT COLLINS